

# CLIMATOLOGY OF DAMAGING LIGHTNING IN ILLINOIS

STANLEY A. CHANGNON, JR.

Illinois State Water Survey, Urbana, Ill.

## ABSTRACT

Statistics on the incidence of damaging lightning in Illinois during the 1914-47 period were gleaned largely from published and unpublished records of the U.S. Weather Bureau to perform a climatological investigation. On the average, damaging lightning was most frequent during July and August. Normally, 14 days per year had damaging lightning, and during the 1926-47 period lightning was responsible for more deaths than any other form of severe weather. Other forms of severe weather occurred on less than 50 percent of the days of damaging lightning. On an areal basis, damaging lightning occurred most frequently in west-southwestern Illinois which is the same area that has been found to have a high incidence of thunderstorms, tornadoes, hailstorms, and excessive rainstorms. Lightning caused deaths and injuries to a greater percentage of the rural population than of the urban population of the State. In rural areas the structures most frequently damaged by lightning were farm barns, whereas in urban areas residences were the structures most frequently damaged.

## 1. INTRODUCTION

Strokes of lightning that occur between clouds and the surface of the earth are one of the most dangerous and damaging forms of severe weather that occur in Illinois. Analysis of 34 years of weather records reveals that on the average lightning in Illinois kills six persons each year and produces property damage amounting to more than \$100,000 annually. In comparison, tornadoes in Illinois during the 1926-52 period resulted in an average of five deaths annually and caused about \$1,200,000 in damages per year [5]. In the 1926-47 period, lightning was directly responsible for the deaths of more people in Illinois than any other form of severe weather. It should be noted that the famous Tri-State Tornado of March 18, 1925, killed 606 persons in Illinois [5], but the data for this event or any of 1925 have not been incorporated in the comparison because of the numerical bias produced by this extremely severe and unusual tornado.

The results of a climatological investigation of damaging lightning in Illinois are presented in this paper. Any day with deaths, injuries, or property losses caused by lightning was considered to be a day with damaging lightning. Averages and extremes of damaging lightning occurrences were determined on an hourly, daily, monthly, and annual basis. The temporal association between the occurrence of damaging lightning and other forms of severe weather was studied. The investigation also dealt with regional variations of damaging lightning within Illinois. The damage data also were analyzed to inspect for variations between different land use areas and different types of buildings.

The data concerning damaging lightning were obtained from published monthly weather summaries of the U.S. Weather Bureau [12] for the 1914-47 period, from newspaper reports, and from the original form 1009 records of

the cooperative observers. In this 34-yr. period the Weather Bureau Section Directors for Illinois prepared written descriptions of the occurrence of all forms of severe weather, and these published records served as the major source for the lightning data summarized in this report. The lightning data listed in these publications are based on information gathered from reports of weather and agricultural observers in Illinois as well as reports from various news media. Comparable records are not available for the years prior to 1914 and after 1947. In the 34-yr. period of records, 463 days with damaging lightning occurred in Illinois.

The quality of the data employed in this study deserves description. The data on deaths and injuries to humans are considered to be quite reliable because the nature of the event usually engenders widespread reporting in the sources of data employed in this study. The reporting of property damage is much less detailed and thereby less representative. Much lightning damage to property goes unreported, and thus the damage statistics presented herein are lower than the actual losses. However, data on the instances of extreme lightning damage are considered relatively accurate. Since the quality of the reporting of property damage should have remained rather constant during the period of study, the damage data are adequate for use in the type of climatological analyses reported on in this paper.

## 2. TEMPORAL VARIATIONS

*Hourly.*—Information on the time of occurrence of damaging lightning was available for only 60 percent of the incidents. However, for those days with time of occurrence data, the maximum number of occurrences was found in the early afternoon, ranging from 1300 to 1600 CST. Very few instances of damaging lightning were

TABLE 1.—*Monthly and annual frequencies of days with damaging lightning in Illinois, 1914–47*

Months	Total number of days	Average number of days in 10-yr. period	Maximum number of days	Total number of days—	
				When 1 or more persons killed	When property damage $\geq$ \$50,000
Jan.....	2	0.6	1	0	1
Feb.....	8	2	2	1	0
Mar.....	17	5	4	1	2
Apr.....	20	6	3	6	1
May.....	45	13	6	20	3
June.....	94	28	12	28	6
July.....	114	34	10	37	2
Aug.....	108	32	9	23	1
Sept.....	36	10	6	8	4
Oct.....	17	5	3	1	1
Nov.....	2	0.6	1	1	1
Dec.....	0	0	0	0	0
Annual.....	463	136	34	126	22

recorded in the hours between 2200 and 1000 CST. The 3-hr. period of maximization of damaging lightning occurrences is earlier in the day than the comparable period for thunderstorms (2000 to 2300 CST), hailstorms (1400 to 1700 CST), and tornadoes (1500 to 1800 CST) in Illinois [8].

*Daily.*—Damaging lightning was found to have occurred either quite frequently or infrequently on certain dates [3]. Such dates can be considered singularities, or dates when the number of incidents over a period of years is relatively higher or lower than the number on other nearby dates. A previous study [3] revealed the dates that rate as statistically significant singularities for days with damaging lightning. In the primary season of occurrence of damaging lightning, which is May 1–September 15, notable dates with a large number of days with damaging lightning include June 18, June 23, July 25, August 8, and August 13. Dates in the same period with a notable lack of lightning incidents include June 29, July 1, July 14–15, and August 21.

*Monthly and annual.*—In table 1 the number of days with damaging lightning per month in the 1914–47 period is shown along with the average number per month during a 10-yr. period. The peak of activity occurred in the summer season, June–August, when more than 46 percent of all the damaging lightning days occurred. In the May 1–September 15 period, 87 percent of all days with damaging lightning occurred.

The months of lightning maximization are July and August, whereas the two months with the greatest frequencies of thunderstorm days in Illinois are May and June [4]. No proven explanation is available for this unusual time disagreement between the two closely related weather phenomena. One possible explanation is that thunderstorms in May and June do not produce as many or as strong cloud-to-ground discharges as do thunderstorms in July and August. Such a difference in lightning frequency could be related to the maximization in July and August of certain climatic conditions which are more conducive to the development of unstable atmospheric conditions and of a greater difference in electrical charge between the earth and the clouds. On the average, the atmos-

TABLE 2.—*Selected days with excessive lightning damage in Illinois, 1914–47*

Date	Number killed	Number injured	Amount of damage, \$	Counties of occurrence
July 24, 1914.....	3	3	50,000+	Cook, Edgar, Vermilion, and Will.
Mar. 26, 1921.....	0	0	350,000	Lawrence.
Sept. 4, 1921.....	1	6	200,000+	Cook, Greene, and Hancock.
June 5, 1924.....	1	4	60,000+	Jersey, McLean, Morgan, Sangamon, Vermilion, and White.
June 22, 1924.....	4	0	50,000+	Cook, Mason, and Peoria.
June 30, 1945.....	0	0	203,000	Adams, Brown, Greene, Logan, and Pike.
Jan. 29, 1947.....	0	1	105,000+	Carroll, Cook, McHenry, Ogle, and Winnebago.

pheric moisture content, the air temperatures, and the presence of warm moist tropical air [6] are at a maximum in July and August in Illinois. Another possible explanation for this temporal discrepancy between thunderstorm and lightning seasonal maximizations could be that the surfaces of structures are more susceptible to damage in July–August than in May–June.

Also shown in table 1 is the maximum number of days with damaging lightning reported in each month and in a single year. The peak number of days for June was 12 which occurred in 1924, for July it was 10 days in 1939, and for August it was 9 days in 1928. The maximum number of damaging lightning days in one year was 34 recorded in 1938. The fewest number in one year was 4 days in 1933. The average number of days per year is about 14.

### 3. DAYS WITH SEVERE DAMAGING LIGHTNING

The monthly number of days when deaths were caused by lightning and number of days when property damages exceeded \$50,000 are also shown in table 1. These data, which serve as a measure of the extremes in severity for days with damaging lightning, were examined to discover any variations from the average monthly frequencies. The monthly frequencies of days with excessive lightning damage indicate that June had the greatest number. June is second ranked to July on the number of days with deaths. Although June had fewer days with damaging lightning than did July or August, the lightning in June appears to have been capable of more severe damage than in July and August.

Lightning in May also produced relatively more severe damages than the May average frequency of damaging lightning days indicates. The death-damage ratio, which is the number of days with deaths plus the days with \$50,000 or more in damages divided by the total number of days with damaging lightning, is 0.51 for May as compared with 0.36 for June, 0.34 for July, 0.22 for August, and 0.33 for September. Thus, approximately one-half of all days in May with damaging lightning produced severe damage, whereas about one-third of the lightning days in June, July, and September were responsible for extremely severe damages.

Some of the days with excessive damages and losses caused by lightning in Illinois during the 1914–47 period are listed in table 2. For these days with severe damag-

ing lightning, many buildings were reported destroyed but no exact monetary loss was reported. Therefore, several of the amounts of damage listed in table 2 are considerably less than the actual amount since the complete figures on total damages are not available. Many of the damages reported were from fires started by the lightning. The excessive monetary loss which occurred on March 26, 1921, was produced when lightning ignited oil storage tanks.

#### 4. DAMAGING LIGHTNING AND OTHER SEVERE WEATHER

The number of times that various forms of severe weather occurred on the dates of the 463 days with damaging lightning was examined to determine the degree of association between damaging lightning and tornadoes, heavy daily rainfalls, and hailstorms. In Illinois a high degree of association has been found to exist between thunderstorms and hailstorms [1], between hailstorms and heavy rainstorms [2], and between tornadoes and hailstorms [8]. Data were readily available on the dates of occurrence of all 3.0-in. or greater daily rainfall, all hailstorms, and all tornadoes in Illinois during the 1914-47 period.

During this period of record, 84 tornado days occurred in Illinois, as compared with 463 days with damaging lightning. Comparison of the occurrence of these two forms of severe weather on the same day was normalized to account for the difference between their number of occurrences. If all 84 tornado days had been days with damaging lightning, a tornado day would have occurred on approximately 1 out of every 6 of the lightning days. However, only 30 of the 463 lightning days were tornado days. Thus, only 1 out of every 15 damaging lightning days was also a tornado day in Illinois.

In the March-October periods of the years from 1914 through 1947 there were 414 days when one or more of the Weather Bureau rain-gage stations in Illinois reported 3.0 in. or more precipitation in 24 hr. A 24 hr. amount of this magnitude is in excess of the amount expected to occur at a point anywhere in Illinois at least once every two years [9]. Only 120 of the 463 days with damaging lightning were also days when a 3.0 in. or greater rainfall was measured somewhere in Illinois. Thus, only 26 percent of the days with damaging lightning were associated with the observed occurrence of heavy rainfall in Illinois.

During the 1914-47 period there were 1,509 days with hail in Illinois as compared with 463 days with damaging lightning. However, only 223 of the days with damaging lightning were also days with hail in Illinois. Thus, 48 percent of the damaging lightning days were associated with the occurrence of hail in Illinois.

#### 5. REGIONAL VARIATIONS IN DAMAGING LIGHTNING

*Areal variations.*—The spatial distribution of damaging lightning occurrences in Illinois was analyzed by counting

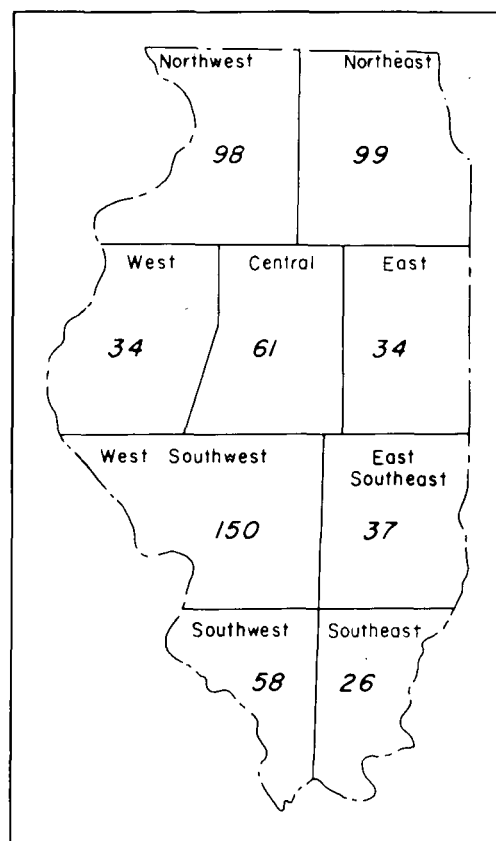


FIGURE 1.—Number of damaging lightning occurrences per section in Illinois, 1914-47.

the number of times damage was reported in each of the nine crop-reporting sections of the State (fig. 1). A count of damaging lightning in a section was made for each point of occurrence if the points or locations of occurrence were separated by distances of 10 mi. or more. Thus, on a given day several occurrences of damaging lightning could be recorded in a section. Consequently, the 463 days with damaging lightning produced damages in 597 separate locations. At each of these 597 locations, property was damaged and/or one or more persons were killed or injured.

The number of occurrences of damaging lightning in each section of the State is shown in figure 1. The West-Southwest Section with 150 occurrences had 25 percent of the State total, and the Northwest and Northeast Sections together accounted for 33 percent of the total. Thus, one-third of the State sections accounted for nearly 60 percent of all the occurrences in Illinois. The Southeast Section had the fewest number of damaging lightning occurrences with only 4 percent of the State total.

The number of damaging lightning occurrences in any area is dependent to some extent on the size of the area and the population of the area. Therefore, the sectional frequencies shown in figure 1 were modified by two normalization procedures to account for variations in the size and the population of the nine sections.

The number of damaging lightning occurrences per 1000 mi.<sup>2</sup> of each section was computed and the results are shown in figure 2. The resulting regional pattern does

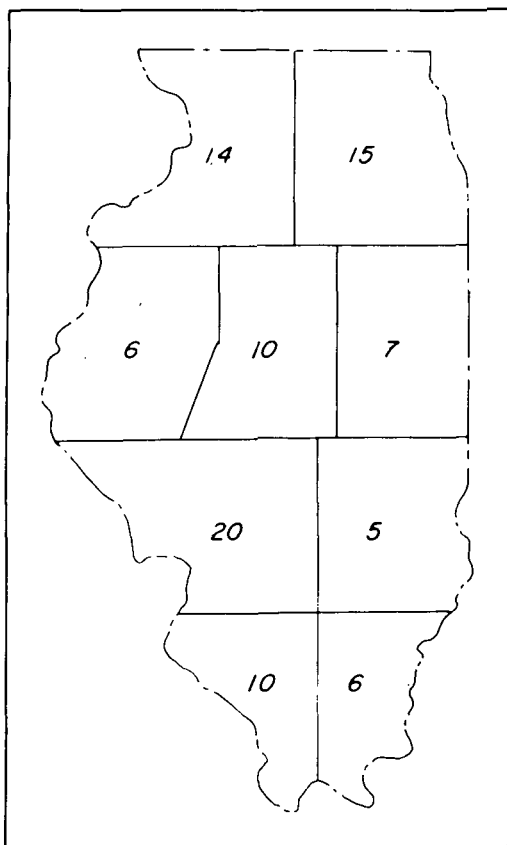


FIGURE 2.—Number of damaging lightning occurrences per 1000 mi.² in each section.

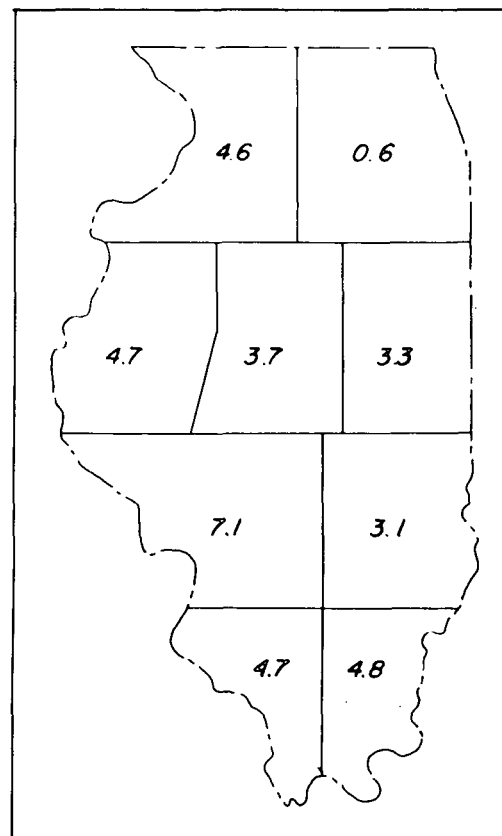


FIGURE 3.—Ratios of damaging lightning occurrences to area-population indices.

not differ markedly from that in figure 1. However, by this means of area-size normalization, the East-Southeast Section rather than the Southeast Section attains the lowest sectional value. The West-Southwest, Northeast, and Northwest Sections still rank 1, 2, and 3, respectively.

The number of damaging lightning occurrences in each section was also normalized to an area size-population factor. Normalization to population was integrated because population density reflects to a certain extent, the number of structures in the section. Therefore, population density serves as a measure of potential structural targets as well as indicating the number of human targets. In each section, the number of occurrences was divided by an Area-Population index to obtain a ratio value. The Area-Population index was derived from the following formula:

$$\text{A-P index} = \frac{(\text{mi.}^2 \text{ of area}) (0.5 \text{ of population})}{1,000,000}$$

The 0.5 and 1,000,000 coefficients in the formula were selected to produce a ratio of a workable size.

The resulting ratio values for each section are indicated in figure 3. The pattern resulting from this normalization is markedly different from those depicted in figures 1 and 2. The West-Southwest Section still retains first rank as the area of greatest frequency of damaging lightning incidents. However, the Northeast Section, which had ranked second, became the lowest ranked with this process of normalization. The enormous urban popula-

tion in the Northeast Section, 62 percent of the State's total, reduces the ratio of this section. This could indicate the incidence of damaging lightning in northeastern Illinois is not strongly related to the population density or to the extensiveness of man-made structures. This may be true because the incidence of losses in an area may decrease after the density of population and structures has increased to the point at which structural sheltering, due to its mode of construction and completeness, offers sufficient protection to reduce structural and personnel losses.

Other differences in the section frequencies are apparent when figure 3 is compared with figure 2. The Southeast Section, which had ranked lowest when normalized to area only, became the second ranked section when normalized by the Area-Population index. In general, the pattern derived from the normalization of occurrences to area size and population density (fig. 3) reveals a diminution in ratio values from the southwest to the northeast across the State. This generalized pattern is similar to the statewide pattern of the average annual number of thunderstorm days which produce 0.10-in. or more precipitation [4].

Results of previous severe weather research in Illinois have shown that the West-Southwest Section of the State is an area where hail [8], tornadoes [5], and heavy rainstorms [10] are most frequent. This area also has the second greatest frequency of thunderstorms in Illinois [4].

The findings of this regional analysis of lightning, which reveal that the West-Southwest Section experiences damaging lightning more frequently than any other sections of the State, confirm and are in agreement with these previous findings.

*Variations by land use classifications.*—The regional variability in the locations of damaging lightning incidents also was investigated by classifying the locations according to different land usages. Three land use classes were selected for differentiation in this analysis: rural, urban (towns of 50 to 10,000 persons), and urban (cities with populations of more than 10,000). In addition, the types of structures damaged by lightning were identified for these three classes of land use.

Any such comparison of lightning damages deriving from land use differences is affected to some extent by the number of targets in each area. That is, a major urban area, as compared with a rural area, has a greater density of population and buildings to serve as potential man or man-made targets. Conversely, a person or a single structure in a rural area could be considered a more likely target because a rural area has a lower density of population and structures. Theoretically, lightning damages per square mile should be slightly greater in an urban area, but an individual structure or person in a rural area would be more apt to be struck by lightning than an individual structure or person in an urban area. To evaluate such possibilities, the findings on damaging lightning occurrences in the land use classes were compared with State values of population and land area for each of the three land use-population classifications.

In table 3 the number of structures damaged or destroyed and the number of persons killed or injured by lightning during the 1914-47 period are shown for the three land use classes. The numbers for each class have also been expressed as a percent of the total structures or persons affected. For purposes of comparison, the land area and population in each land use classification have been expressed as a percent of their respective State totals. The State land percentages for the classes were derived from 1940 census statistics [11]. The population statistics were calculated from 1950 census data [7]. Land use and the population distribution varied somewhat in Illinois during the 1914-47 period, but the percentages shown in table 3 are considered representative of the conditions which existed throughout the period of investigation.

The two urban area classifications comprised 5 percent of the total land area and yet 46 percent of the structures damaged by lightning in Illinois were in urban areas. This disparity in percentages indicates that the greater density of structures in urban areas results in a greater frequency of lightning strikes to structures in a square mile of urban area than in a square mile of a rural area. To normalize correctly these structure percentages, data on the total State number of structures in each land use class are needed, but are unavailable.

Deaths and injuries in urban areas accounted for 72

TABLE 3.—Number of occurrences of damaging lightning in different land use classes in Illinois

Land use class	Structures damaged or destroyed			Persons killed or injured		
	Number	Percent of total number	Percent of State area	Number	Percent of total number	Percent of State population
Rural.....	336	54	95	90	28	4
Urban, towns*	123	20	1	101	31	21
Urban, cities*	158	26	4	131	41	75
Total.....	617	100	100	322	100	100

\*Populations of 50 to 10,000 for towns, and greater than 10,000 for cities.

percent of the total deaths and injuries caused by lightning. Yet the urban areas contained 96 percent of the total State population. The rural areas with only 4 percent of State population experienced 28 percent of the total deaths and injuries. These disparities in percentages (table 3) indicate that rural areas, and small towns as well, experienced relatively more lightning-caused deaths and injuries than did major urban cities. In conclusion, it appears that lightning causes damages to structures in an urban area more frequently per unit area than in a rural region, but lightning kills and injures relatively more people in rural areas and small towns than in major urban areas.

The damages to various types of structures in each land use class were noted and were grouped according to function such as industrial, commercial establishments, residences, etc. The resulting statistics are shown in table 4.

The number of each type of structure was also expressed as a percent of the total number of structures in each land use class, and these percentages allow comparison of the frequencies between classes. For instance, 40 percent of the structures damaged in major cities in Illinois were residences, whereas only 28 percent of the structures damaged in small towns were residences. In rural areas, farm buildings experienced more than 80 percent of the total damages to structures. Of the 277 farm buildings in rural areas damaged or destroyed by lightning, 252 were barns. Thus barns, which are normally the tallest buildings in groups of rural buildings, are the rural structures most susceptible to lightning damage. The major differences between structures of large and small urban communities relate to the percentages for residences and for churches and schools. Churches and schools in small towns suffered lightning damages much more frequently than did those in large cities and rural areas. This may be a reflection of the fact that churches and schools in small towns often are the tallest structures. Of interest was the fact that industrial structures experienced a very low percentage of the total lightning strikes in all classes of land use. For the State as a whole, farm buildings and residences accounted for 67 percent of the structures which were damaged or destroyed by lightning. The destruction of a structure by lightning was usually accomplished by a fire which was caused by the lightning strike.

TABLE 4.—Number of times various structures were destroyed or damaged by lightning in Illinois, 1914–1947

Land use class	Types of structures or objects						
	Residences	Schools and churches	Industrial	Commercial	Vehicles	Farm buildings	Others*
Rural:							
Number.....	20	6	2	10	4	277	17
Percent.....	6	2	-1	3	1	82	5
Urban, towns:							
Number.....	34	14	6	21	2	18	28
Percent.....	28	11	5	17	2	15	22
Urban, cities:							
Number.....	63	7	12	36	3	0	37
Percent.....	40	5	7	23	2	0	23
Total:							
Number.....	117	27	20	67	9	295	82
Percent.....	19	4	3	11	2	48	13

\*Indicates structures damaged or destroyed but type of building function unknown.

## 6. CONCLUSIONS

A climatological study of lightning which produced property damages and/or deaths and injuries to persons in Illinois was performed using 34 years of Weather Bureau records. From 1926 to 1947 lightning was responsible for more deaths in Illinois than any other form of severe weather including tornadoes. On the average, six people were killed and four were injured each year in Illinois.

Damaging lightning occurred most frequently from 1300 to 1600 CST and very infrequently in the 12-hr. period beginning at 2200 CST. In the 1914–47 period certain dates including June 18 and 23, July 25, and August 8 experienced many more occurrences of damaging lightning than other dates.

Nearly 50 percent of all damaging lightning days occurred in the summer season with the greatest number in July. This is one month later than the month of maximization of thunderstorms in Illinois. Although June had fewer days of damaging lightning than July or August, the amount of damage caused by lightning in June was greater than in July or August.

Other forms of severe weather did not frequently occur in Illinois on the days when damaging lightning occurred. Heavy 24-hr. rainfalls occurred in the State on only 26 percent of the days with damaging lightning. Only 40 percent of the tornado days in Illinois were associated with damaging lightning, and on 48 percent of the lightning days hail occurred. The lack of daily association between hailstorms, tornadoes, and damaging lightning is not too unexpected since hail and tornadoes occur most frequently in Illinois in the March–May period which is two to three months earlier than the maximization period of damaging lightning. However, the maximum season of occurrence of the heavy 24-hr. rainfalls is June–August which is identical with the preferred season for damaging lightning.

Damaging lightning occurrences were most frequent in west-southwestern Illinois where other forms of severe weather have been noted to occur most frequently. Damaging lightning occurrences were also quite frequent in northern Illinois and were most infrequent in east-

southeastern Illinois. After the number of damaging lightning occurrences in nine State areas were normalized to area size and population, the high frequency in heavily-populated northeastern Illinois was greatly reduced which indicates that the number of damaging lightning occurrences is not greatly affected by the density of population, at least in an area where the density of population and structures is quite high.

Investigation of the variations in damaging lightning occurrences between different sized urban communities and rural areas revealed that lightning damaged the structures in urban areas more frequently per unit area than it did in rural areas. However, lightning killed and injured relatively more persons living in rural areas and small towns than it did in major cities in Illinois. Nearly two-thirds of all structures damaged by lightning or destroyed by the ensuing fires were residences and farm barns. Barns accounted for nearly 90 percent of all structures damaged by lightning in rural areas. Forty percent of all structures damaged or destroyed by lightning in major Illinois cities were residences.

## ACKNOWLEDGMENTS

The author wishes to express his gratitude to Mr. Eugene A. Mueller and Mr. Glenn E. Stout of the Illinois State Water Survey for their pertinent suggestions concerning this manuscript. This research was accomplished under the direction of Mr. William C. Ackermann, Chief of the Illinois State Water Survey, and Mr. Glenn E. Stout, Head of the Meteorology Section.

## REFERENCES

1. S. A. Changnon, "Areal Frequencies of Hail and Thunderstorm Days in Illinois," *Monthly Weather Review*, vol. 90, No. 12, Dec. 1962, pp. 519–524.
2. S. A. Changnon, "Severe Summer Hailstorms in Illinois During 1915–50," *Transactions Illinois Academy of Science*, vol. 53, Nos. 3–4, 1960, pp. 146–156.
3. S. A. Changnon, "Singularities in Severe Weather Events in Illinois," *Research Report 13*, Crop-Hail Insurance Actuarial Association, Chicago, Ill., 1962, 19 pp.
4. S. A. Changnon, "Thunderstorm-Precipitation Relations in Illinois," *Report of Investigation 34*, Illinois State Water Survey, Urbana, Ill., 1957, 24 pp.
5. S. A. Changnon and G. E. Stout, "Tornadoes in Illinois," *Circular 63*, Illinois State Water Survey, Urbana, Ill., 1957.
6. I. M. Chiang, *Analysis of Selected Synoptic Elements of the Climatology of Illinois*, Masters Thesis, Southern Illinois University, Carbondale, Ill., 1962, 75 pp.
7. Hixson Map Co., *Plat Book of Illinois*, Rockford, Ill., 1951, 61 pp.
8. F. A. Huff and S. A. Changnon, "Hail Climatology of Illinois," *Report of Investigation 38*, Illinois State Water Survey, Urbana, Ill., 1959, 46 pp.
9. F. A. Huff and J. C. Neill, "Frequency Relations for Storm Rainfall in Illinois," *Bulletin 46*, Illinois State Water Survey, Urbana, Ill., 1959, 65 pp.
10. G. E. Stout and F. A. Huff, "Studies of Severe Rainstorms in Illinois," *Proceedings of ASCE, Journal of the Hydraulics Division*, vol. 4, No. 7, July 1962, pp. 129–146.
11. U.S. Bureau of Census, *Statistical Abstract of the United States: 1961*, 82d Edition, Washington, D.C., 1961, pp. 615–616.
12. U.S. Weather Bureau, *Climatological Data for Illinois*, vols. 19–53, 1914–1947.

[Received July 25, 1963; revised November 20, 1963]